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# The influence of the loop power-flow on the tires' life span of a vehicle

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**Abstract**

This paper provides an analysis of the influence of the loop power-flow on the vehicle's tire life span with respect to the domain of the sustainable development. The first part of the paper presents a series of theoretical notions defining and expressing the analyzed elements. The second part presents the ways the vehicle has been prepared from the experimental point of view to collecting the necessary data. The last part reveals numerous relevant conclusions regarding the way the vehicle tire's way of use is influenced by the loop power-flow within the transmission. Moreover, the tire's life span, with its characteristic features has certain impact upon the environment and economy, generally speaking. The present paper tries to reveal some of this impact's components.

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*Keywords:* transmission; loop power-flow; tire; slip; sustainable development.

## 1. Introduction

In this paper we tried to reveal the way the loop power-flow, generated between a 4x4 vehicle' axles, influence the life span of its tires, with respect to the sustainable development concept. The tire's life span is

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strictly analyzed from the wheel's traveled distance (in kilometers, of course) before becoming too worn out (according to the law's regulations).

The *loop power-flow* is the power that loads a closed loop of the transmission driveline and it is not generated by the automobile's engine or by the coasting process of the vehicle. Mathematically speaking, it is computed by multiplying the self-generated torque on some component with that component's angular speed [Truţă et al., 2012].

To have a 4x4 vehicle with loop power-flow within its longitudinal transmission, it has to travel with its' inter-axle differential locked while its wheels travel different distances. Since the military vehicles are currently off-road moving, they need a high capacity of progression. Hence, the typical conditions for the loop power-flow occurrence are frequently met.

References [2, 3] prove that using a vehicle in such circumstances (that generate loop power-flow within the driveline) lead to wheels' either slipping or skidding.

Taking into account the aim of this work, we should previously define the term. Concept 80 of sustainable development, as it was defined by the World Commission on Environment and Development (WCED) in the well known Bruntland Report [Report of the World Commission on Environment and Development] specifies: *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. Sustainable development consists of three major poles: the economic one, the social one and the environmental one.

Being aware of the fact the tires are made of materials coming, more or less, directly from the nature, analyzing the factors and phenomena that influence their life span becomes of major interest.

**Nomenclature**

| | |
|---|---|
| $a$ | relative skid |
| *WCED* | World Commission on Environment and Development |
| $\eta_T$ | transmission's efficiency |
| $\phi$ | grip coefficient |
| $Z_S$ | normal force on the vehicle's rear wheel |
| $r_r$ | rolling radius of the wheel |
| $\omega$ | angular speed (velocity) |
| $P$ | power |
| $M$ | torque; engine |
| $F, f$ | front |
| $S, s$ | relative slip; spate |
| $\Delta r$ | wheels radii difference |

The main material a tire is made of is the rubber (natural and/or synthetic). Textile and metallic materials are also used to manufacture a tire. Concerning all these materials, to increase the positive impact on the environment and on the national/global economy, prolonging the life span of a tire becomes a must. Should also be taken into account that the recycling procedures of tires are, at least so far, quite polluting since not all the components of a worn tire can be properly recycled.

## 2. Mathematical notions

### *2.1 Basic kinematics of the wheel*

When a pneumatic wheels rolls on a typical runway (surface), complex phenomena occur. They are rather difficult to become subject of accurate mathematical expressions due to the vastness of the involved factors. Among the most important factors we find suitable to mention the tire's deformation and/or the runway surface's deformation.

The following analyze assumes that both the wheel and the road's surface are completely stiff (no deformation occurs). The technical references [Marinescu, 1999], [Gorianu, 1992] reveal three general situations one can find the wheel in its rolling process: ideal rolling (fig. 1-a), slipping rolling (fig. 1-b) and

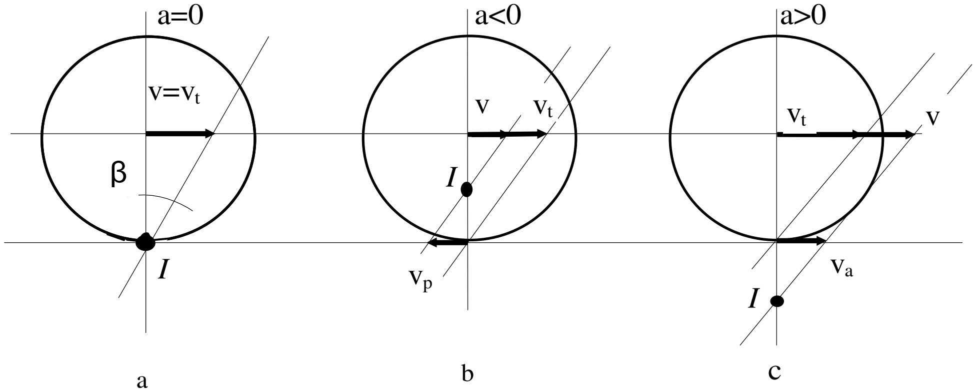



Fig. 1. Wheel's rolling situations a) ideal rolling; b) slipping rolling; c) skidding rolling; I – instant gyration center; v – real speed; $v_t$ – theoretical speed; $v_a$ – skidding speed; $v_p$ – slipping speed

skidding rolling (fig. 1-c).

Fig. 1-a depicts the ideal case of a stiff wheel that rolls on a stiff runway surface, neither slipping nor skidding. In this case, the instant gyration center is placed in the contact point between the wheel and the road. The real speed of the wheel equals the theoretical one according to equation $v= v_t$. Hence, the absolute speed of the wheel and its theoretical one are the same.

The slipping rolling of the wheel (fig. 1-b) differs from the ideal one because the instant gyration center migrates towards the wheel's spinning center. That is due to the fact a slipping speed occurs within the contact point between the wheel and the runway. This slipping speed points in the opposite direction of the wheels center motion. The absolute speed is obtained by subtracting the slipping speed from the theoretical speed, using equation $v = v_t - v_p$; $v < v_t$.

The last situation is featured by the migration of the instant gyration center below the point of contact of the wheel with the runway surface (fig. 1-c). The skidding speed points towards the same direction with the wheels' center speed; hence, the absolute speed is obtained by adding the skidding speed to the theoretical speed as given by the equation $v = v_t + v_a$; $v > v_t$. Therefore, the absolute speed is higher than the theoretical one.

The argument is complete if we consider the absolute speed (i.e. the wheel's center speed) to be the vehicle's speed, since the wheels are rigidly connected to the chassis, with respect to the longitudinal axis of the vehicle.

The relative slip [Marinescu, 1999] is defined by

$$a = \frac{v - v_t}{v_t} \tag{1}$$

The relative skid [Marinescu, 1999] is defined by

$$s = \frac{v_t - v}{v_t} \tag{2}$$

Under certain circumstances, pure slip or pure skid could occur. Pure skid is defined by null theoretical speed ($v_t=0$) while the skidding speed is positive ($v_a>0$). This situation, in practice, is given by the vehicle in motion, with blocked wheels ("sledding"). Pure skid situation occurs when the vehicle is standing still (motionless) and its wheels are spinning. This case is mathematically described by a null absolute speed ($v=0$) and a positive theoretical speed ($v_t>0$).

*2.2 Basic of the loop power-flow computation*

Self-locking differentials, as well as lockable ones, can lead, under certain circumstances, to self-generate torque that generates, at its turn, loop power-flow. This power is always a harmful phenomenon since it overloads the transmission components, increases the tire's worn and reduces the vehicle's maneuverability. As we have already mentioned, the main factor leading to self-generated torque occurrence is the unevenness of the distances traveled by the vehicle's wheels when the transmission works with its differentials in locked (or self-locked) mode.

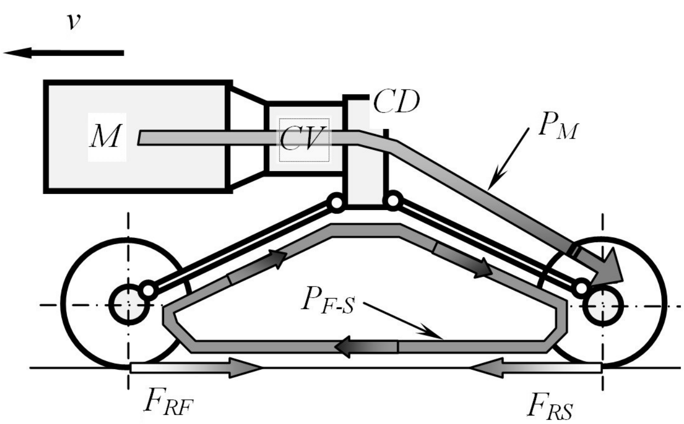



Fig. 2. Power flows within a 4x4 vehicle transmission with power loops
M – engine; A – clutch; CV – gearbox; RD – transfer case with open, lockable differential;
$\sum R$ – total drag; v – vehicle's speed; $P_{mot}$ – engine's output power;
$F_{R_F}, F_{R_S}$ – driving forces at front and rear axle, respectively; $P_{F-S}$ – loop power-flow between axles

Thus, when the vehicle is moving straightly and its wheels have different rolling radii between the front and rear axles while its inter-axle differential is locked, loop power-flow occurs, as depicted in fig. 2.

The power balance in this case is given by

$$P_{mot}\eta_{T_{M-S}} = \phi Z_S r_{r_S}\omega_r - \left(\phi Z_S - \sum R\right) r_{r_F}\omega_r\eta_{T_{F-CD}} \quad (3)$$

where:

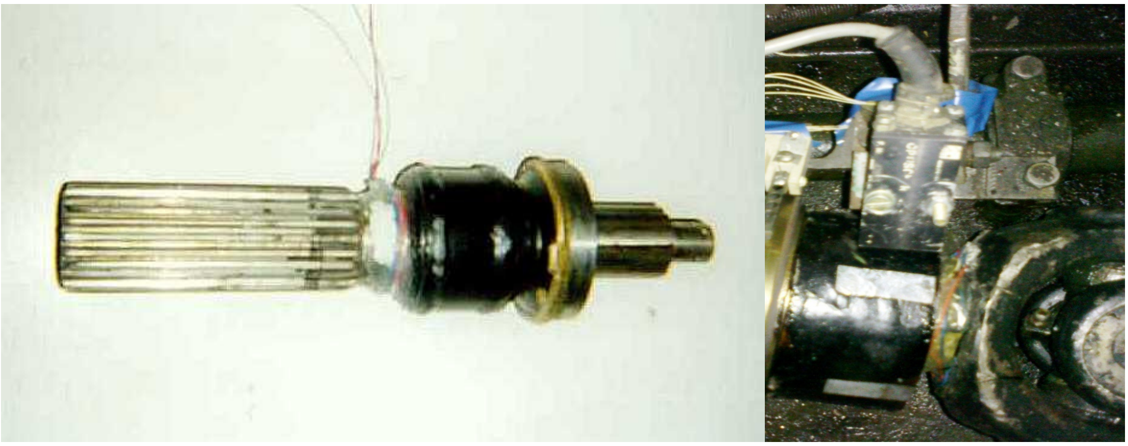
- $P_{mot}\eta_{T_{M-S}}$ - is the power the engine delivers to the transfer case;
- $\varphi Z_S r_{r_S}\omega_r$ - the power “accepted” by the road’s grip;
- $\left(\varphi Z_S - \sum R\right) r_{r_F}\omega_r\eta_{T_{F-CD}}$ - loop power-flow.

## 3. Mounting the transducers on the vehicle for experimental research

This part of the paper reveals the way about the way we’ve placed our transducers on the vehicle and about the measuring, data storing and processing equipment. The transducers measure the self-generated torque as well as the angular velocities of different components of the vehicle’s drivetrain. The angular speed transducers offer the values of different shafts angular velocities as well as the wheels’ angular speeds. The wheels’ angular speeds are also used to compute the skid/slip values. Eventually, this chapter presents the procedure of checking the value of the index providing information with respect to the tire’s life span.

Since the loop power-flow occurs under the circumstances we’ve already introduced, a 4x4 with a longitudinal lockable differential military vehicle was chosen. When testing the vehicle, its inter-axle differential was locked. This differential is placed in the transfer case.

Knowing that the power flow received by the transfer case from the engine is transferred to the axles via a propeller shaft system, we’ve set the needed the transducers to reveal the phenomenon.



a b

Fig. 3. (a) Strain gauge torque transducer; (b) Optical transducers for angular speed

Fig. 4. Measuring of the depth of the tire tread grooves

Since the power is given by $P = M \cdot \omega$ (where $P$ is the power, $M$ is the torque and $\omega$ is the angular speed of the shaft), a set of torque transducers and another one of angular speed were placed on these shafts. Fig. 3-a depicts de setting places [Truţă, 2013] for the torque transducers (strain gauges, Wheatstone-bridge configured). Angular speed was measured with the aid of some optical transducers [Truţă, 2013] as depicted in fig. 3-b.

To determining the relative motion between the wheel and the runway surface (slips, skids) we also needed the absolute speed of the vehicle. We measured it using a GPS device.

The tire wear index is used to assessing the remaining of their life span. There are several methods to perform this assessment, but the most expressive is the one that involves the measuring of the depth of the tire tread's grooves (fig. 4). A common device (slide caliper) is used in this respect.

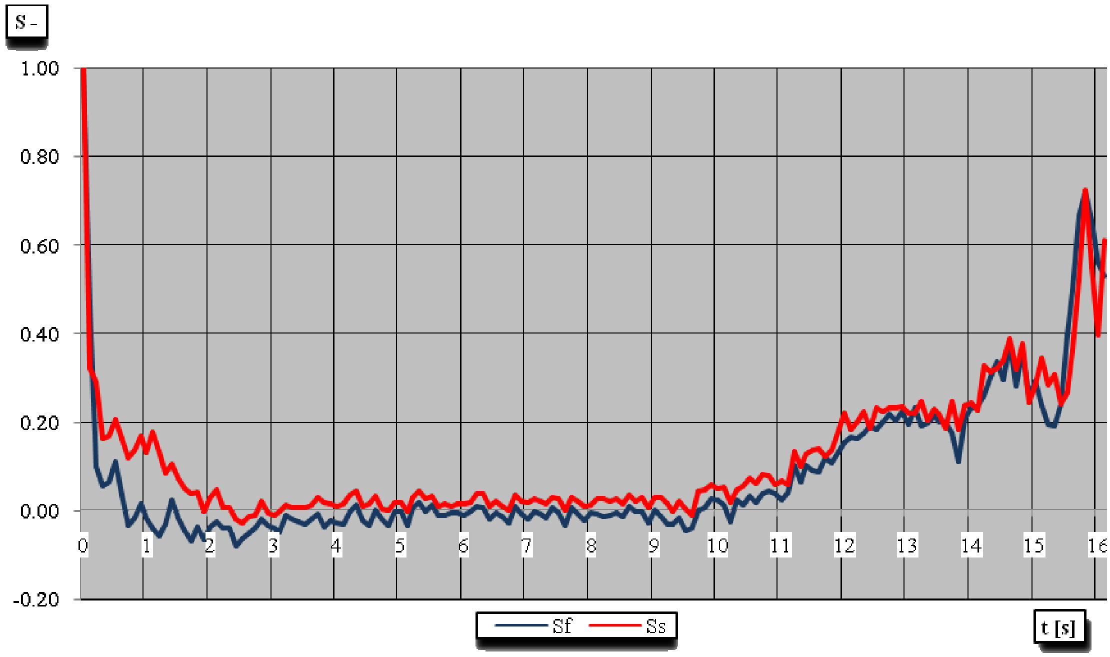
## 4. Experimental results

The experimental results given in this part of our work prove that using a 4x4 vehicle with its inter-axle differential working in the locked mode while its wheels have different rolling radii between axles will certainly lead to the loop power-flow occurrence. The results hereby presented feature the situation of a tire radii difference of 30 mm between the front and rear wheels ( $\Delta r = 30$ mm).

This loop power-flow is given in fig. 5-b (blue curve, Pf). On the other hand, the loop power-flow as a result of a cinematic misfit (uneven wheel radii, uneven traveled distances) generates skid/slip of the wheels. They are depicted, as an example, in fig. 5-a.

A mention should be made with respect to the curves depicted in fig. 5. The positive values of the powers feature them as driving power while the negative ones lead to loop power. A pure skid of the wheel is defined by S=1, a pure roll is given by S=0 while pure slip is featured by S=-1. Moreover, it is commonly accepted that, for values of the S parameter up to 0.2 (absolute values), we speak about "micro-skid/micro-slip". If S parameter ranges between 0.2 and 1.0 then we speak about "macro-skid/macro-slip" or just "skid/slip".

The final step assumes an assessment of the degree of influence the loop power-flows within the vehicle's transmission influence the tires' wear. Consequently, this will be strongly connected to the life span of the tires. Therefore, a number of similar vehicles have been subject to analyze. Throughout this analysis we identified that bulk of vehicles that mainly worked with loop power-flow in their driveline and we separated them from the other group, the one of those vehicles that worked mainly in a proper way. We measured the tires' wear levels for all the vehicles, taking into account the particular mileage of each vehicle with the same set of tires.

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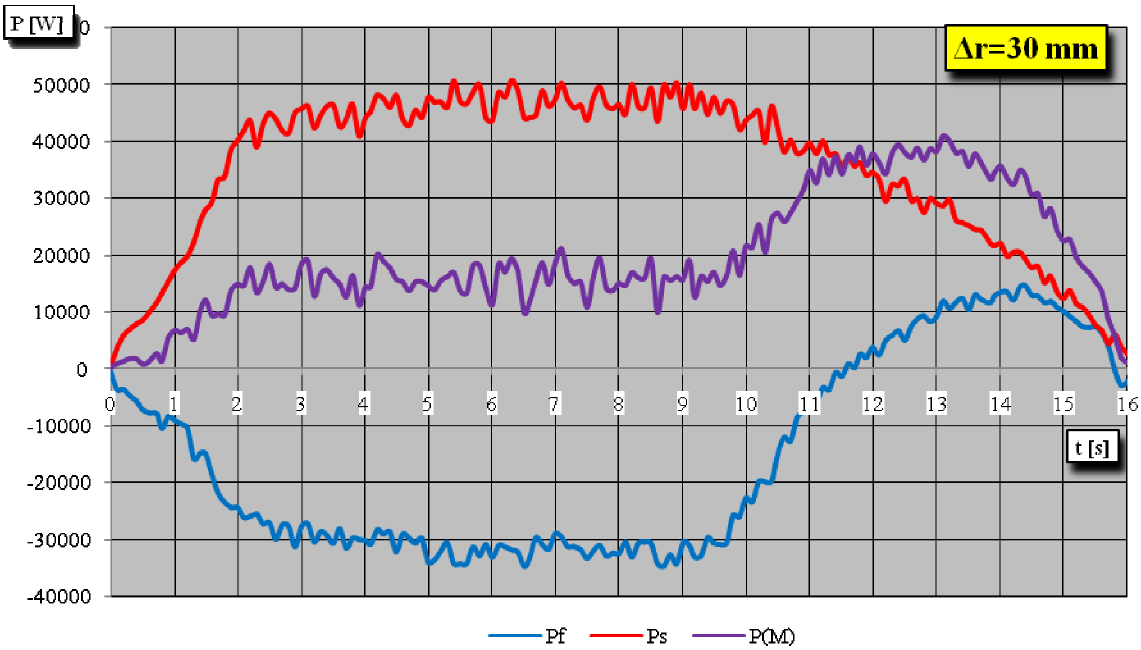


b

Fig. 5 – The loop power-flow and wheels' slip
P – power; P(M) – engine power; t – time; Pf – power on the front axle's driving shaft (loop power-flow);
Ps – power on the rear axle's driving shaft; S – wheels' slip; Sf – front wheels' slip; Ss – rear wheels' slip.

After performing the measurements, we noticed that the tires working on the vehicles that mainly ran with loop power-flow within their drivelines are having a wear degree of about 18% higher than the other ones, at the same traveled distance. On the other hand, we should mention that the value of 18% couldn't take exclusively into account the loop power-flow but other factors as well. Nevertheless, we could say that these other factors are rather insignificant compared to the wheels' skid/slip due to the cinematic misfit, if the tires' wear was considered.

According to the reference [Ghiulai et al., 1975], the relative motion between the tire and the runway surface (skidding or slipping) will lead to an increase of the power losses and will increase the tire (and road's surface consequently) wear.

## 5. Conclusions

Using the vehicles under circumstances that generates loop power-flows within the longitudinal (inter-axle) transmission (driveline) of an all-wheel-driven vehicle leads to wheels' skid/slip on the runway surface. Wheel's skid/slip is the major factor that generates the higher rate of tire wear.

Fast wear of the tires reduces their life span. The tires of the vehicles that mainly worked with loop power-flow within their drivelines present an 18% higher degree of wear than the vehicles running in mainly normal conditions. And this is an essential impact factor upon the economy and environment.

The impact upon the environment is featured by the increasing consumption of natural resources to manufacturing new tires. Also, should be taken into account the pollution due to the recycling process of the tires that, at this level of technological development, still lacks in performance.

Economically speaking, if the tires have a shorter life span, the costs of using a vehicle will increase accordingly.

Considering all the facts we hereby presented, two major choices are obvious. We either find some technical solutions to make a compromise between the need of high-ability, off-road vehicles (that wear tires) or avoid using these vehicles in the modes implying loop power-flow.

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